February 8, 2006

Silver Fox Flight Demonstration Project
February 13 to 19, 2006

Summary of Mission Objectives

Project Scientists:	Steve Gittings	(NOAA/NOS/NMSP)
	David Wiley	(NOAA/NOS/NMSP)
	David Matilla	(NOAA/NOS/NMSP)
Principal Investigators:	Dan Basta	(NOAA/NOS/NMSP)
	Todd Jacobs	(NOAA/NOS/NMSP)
	Steve Gittings	(NOAA/NOS/NMSP)
Project Manager:	Todd Jacobs	(NOAA/NOS/NMSP)

(NOS) National Ocean Service
(NMSP) National Marine Sanctuary Program

1.0 Background.

Unmanned aerial systems (UASs) have great potential to meet NOAA's mission requirements in the coming years. UASs will be complementary to existing ground-based, airborne, and space-based systems. Important requirements identified in the NOAA 2005-2010 Strategic Plan that can be addressed by UAS platforms and their sensor payloads include fisheries monitoring and enforcement, surveillance, and ecosystem monitoring.

This project supports the following Annual Guidance Memorandum Priorities:

Taking the Pulse of the Planet-
- e. Develop new techniques and measurements
- i. Direct resources and research toward exploring new technologies

Advance NOAA's Modeling Capability
- b. Support research to operations
- c. Develop and apply advanced data assimilation techniques

Provide Leadership for the Oceans
- c. Improve existing regional coordination across NOAA and with other agencies

Deliver Effective, Efficient Decision-Support Information
- a. Maximize the contribution of science and technology
- b. Investigate, develop, and expand use of new technologies
- e. Review operational concepts and identify opportunities for efficiencies

This project supports the following DOC strategic goals:

2.1 Develop tools and capabilities that improve the productivity, quality, dissemination, and efficiency of research

UASs are a relatively new asset available to NOAA research and operations. The importance of adding UAVs and newer technology to NOAA's mission is described in the 2007 Annual guidance Memorandum from the NOAA Administrator (VADM Lautenbacher):

> "*We must move new but proven observing systems into an operational environment and redirect associated resources and research toward exploring new technologies, such as unmanned aerial vehicles, to meet future requirements*."

To this end, a series of flights on Advanced Ceramics Research, Inc.'s (ACR) Silver Fox and Manta UASs is being planned for February of 2006. The purpose of the 2006 Silver Fox and Manta trials is to demonstrate the use of a Low Altitude Short Endurance (LASE) UAS to support NOAA, NOS and NMSP scientific and operational needs. The Silver Fox payload consists of optical and infrared surveillance systems. Several mission flights are planned to evaluate the Silver Fox's ability to perform the following missions:

- Detection, observation, and identification of vessels, including determination of their activities (fishing, pleasure boating, etc)
- Detection, observing, and geo-locating shallow underwater features such as coral bleaching and groundings.

- Detection, observation, and tracking of oil spills, algae blooms, and other surface features.
- Detection, observation, and tracking surface dwelling living resources, such as marine mammals

The purpose of this document is to summarize the mission objectives for both the science and operational uses.

1.1 The NMSP Operational and Science Missions.

The National Marine Sanctuary Program was created in 1972 and is administered by the National Oceanic and Atmospheric Administration (NOAA.) Currently, these sanctuaries include over 18,000 square miles of water and marine habitats. There are plans to create a new sanctuary in the Northwest Hawaiian Islands, currently the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve, encompassing nearly 120,000 square miles. Patrolling this large an area for illegal fishing and other activities presents many challenges.

The NMSP has numerous operational requirements that could be met using UAS technology. Staff regularly responds to animals in distress, such as whales that become entangled in fishing gear or marine debris. In such cases, it is often difficult to monitor the location of the animal for the extended period that may be required for response. The same is true for hazardous spills. It is sometimes necessary to track and measure sediment plumes caused by human activities, such as road construction and repair and dredging. Harmful algal blooms must be assessed and tracked to determine the threat they pose to resources and humans. The extent of damage caused by coral bleaching or vessel groundings can also be evaluated from the air. Vessel traffic monitoring is sometimes necessary to limit threats to migrating or congregating animals. Monitoring vessel activity, such as fishing, recreational boating, diving, and cargo transit is necessary to understand uses and threats to sanctuary resources.

The NMSP also has scientific needs in a number of areas that can be addressed by UAS flights with camera payloads. Resource characterization needs include:

- identification and measurement of shallow water habitat types;
- documentation influences of watersheds and other inputs that affect water quality;
- temporal and spatial patterns of habitat use by living resources (e.g., haul out areas); and
- population assessments for large animals, such as birds and marine mammals.

Representative monitoring requirements for the NMSP include:

- periodic collection of data along predetermined flight paths to count birds and marine mammals;
- overflights of known haul out and bird nesting areas;
- documenting changes in kelp canopy cover;
- determining the location and extent of potentially productive convergence zones or upwelling areas;
- determining spatial and temporal affects of runoff; and
- counting vessels and assessing human use patterns.

The flight demonstration project with the Silver Fox will include instruments for observing and counting shallow subsurface features, surface features, living resources, and vessels. The Silver Fox UAS will use an Electro-Optical Infrared (EO/IR) Sensor to determine to what extent these operational needs could be met in future UAS flights. The demonstration will focus on the Hawaiian Islands Humpback Whale National Marine Sanctuary off the coast of Upolu Point, on the Island of Hawaii, HI. The EO/IR system may also be assessed for its ability to conduct day and night fisheries surveillance and enforcement, and selected marine mammal surveys.

Table 1. Silver Fox Instrument Package

Operational Sensors		
Optical Camera System	CCD Video camera	Surveillance, monitoring and counting
Electro-Optical Infrared sensor (EO/IR)	Visible and infrared sensors with pointing capability	Searching and observing

Understanding that it would be impractical to attempt to address all the potential uses of this system in a demonstration project, the following subset of capabilities are proposed for the initial effort:

- documentation of number, location, and type of ships and boats at sea;
- assessment of detection limits for marine debris (e.g., minimum size of entanglement on a marine mammal);
- remote detection and counting of humpback whales on the ocean surface;
- mapping of shallow water habitats; and
- mapping of plumes at sea.

Humpback Observations:
All observations will be made from above 300m (1000 feet), except during takeoff and landing, or when fortuitous encounters occur during operations not focused on humpbacks. Flyovers will be conducted in areas know to contain humpback whales. Initial operations will involve determining the quality of observations of individuals (adults and calves) from these altitudes, and whether particular behaviors can be identified and monitored (e.g., holding position over a surface active group.) In order to locate whales offshore, shore-based observers with binoculars may report the general locations of whales in order to direct the aircraft.

If this pilot effort suggests that lower altitudes are required to make definitive observations of whales and behaviors, future efforts will be designed to conduct such evaluations. If the video observations prove satisfactory, the aircraft will be flown on transects in order to determine the conditions under which systematic surveys might be conducted. The aircraft will navigate calm, choppy, and wind-blown waters in order to begin to assess effectiveness under differing conditions. Although ground truthing may not be available, it should be possible to assess the uncertainty with which observations suggest whales and the extent to which behaviors can be distinguished. If possible, an operation using the IR camera should be conducted in order to evaluate the possibility of detecting warm blooded animals at the sea surface.

Vessels:
Overflights of areas with vessels will be made in order to determine how well the aircraft detects vessel number, size, and type from differing altitudes. Shore-based and/or boat-based observers will provide ground-truthing, if possible. Small boat harbors, if available, would provide a good opportunity to collect information that could be verified. The effectiveness of the IR camera in detecting vessels should also be evaluated.

Marine Debris:
If a small boat is available, it should be possible to secure a collection of marine debris in order to evaluate the systems ability to detect various types and sizes of debris. The boat would simply trail the debris very slowly, or sit idling, while the aircraft flies over at several altitudes. As part of the test, a series of trailing lines in decreasing densities would allow operators to judge how well entangled whales could be detected from the air.

Benthic Mapping :
We will attempt to delineate nearshore habitats from several altitudes and in differing weather (wind), sea state, and water clarity conditions. Snorkelers will provide ground-truthing, if safe and appropriate. Flyovers will be conducted first, and snorkelers will be sent to specific sites to determine habitat types and depths.

Plume Mapping:
Any plumes from discharges, blooms, convergence, or wind stress seen from the air or shore will be imaged. If a small boat is available, it will be sent to the plume to provide scale for measurements. Flyovers from different directions will be conducted in order to ascertain the best camera angles for detection.

Support Requirements:
Some of these evaluations would be best accomplished with the deployment of at least one support boat. In such cases, observations would be ground-truthed, with instructions sent from shore-based operators to vessel crews. The vessel would not need to venture out of sight of the shore crew. Shore-based crews may be deployed temporarily to high ground in order to spot whales, boats, and plumes, or to nearshore habitats to assess types and depths of habitats imaged by the aircraft. They will use hand held VHF radios or cell phones to communicate with aircraft operators and boat crews.

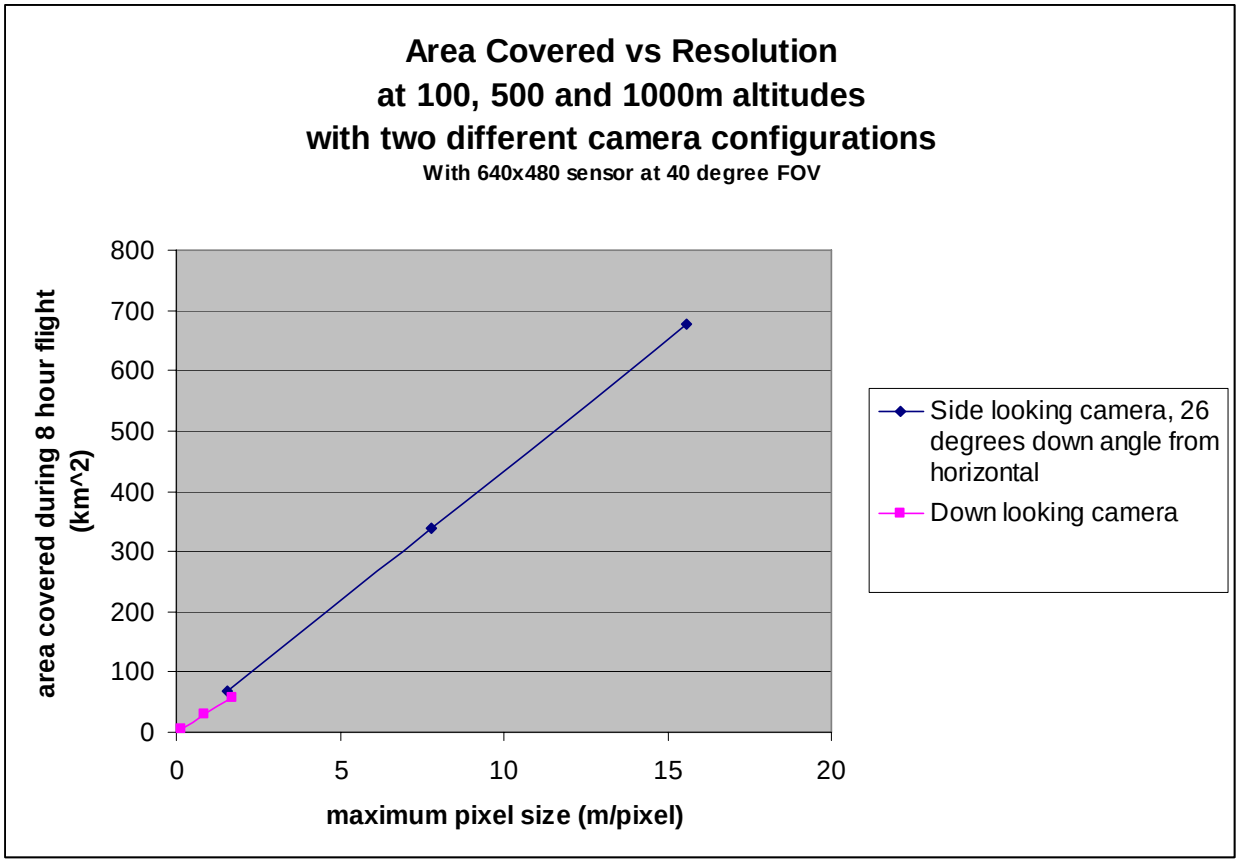
2.0 Operational Instruments and Objectives.

2.1 EO/IR Camera

Description: The Electro-Optical Infrared (EO/IR) Sensor contains two instruments for exploiting visible and non-visible wavelengths. One channel operates in the visible (color zoom) and one in the infrared. This provides day/night assets that can be used for fisheries enforcement as well as reconnaissance. Flights at 300 feet and above will be flown over the water off of Upolu Point for a resolution of down to 20cm. Lower flights may be required for specific

identification of commercial and recreational fishery vessels, and other items of interest (marine mammals, marine debris, etc) that are in or transiting the sanctuary waters. At an altitude of 100 feet, the pixel resolution is 5 cm.

Figure 1. Area Covered vs. Resolution



Observables: 1) Humpback whale surveys, 2) Humpback whale identification, 3) Day/night fisheries surveillance/enforcement, 4) Vessel identification.

Figure 1, above, shows the tradeoff between minimum resolution of the camera and total area searched. For example, if a 2.5 meter resolution is sufficient to detect a whale, approximately 100 square kilometers of area can be covered by the EO camera in a single flight. If the target is a fishing vessel, and a 5 meter resolution is sufficient, approximately 200 square kilometers can be covered. Once an object is detected, the aircraft can be directed to fly lower and increase camera zoom level for a higher resolution image of the object. This may be to attempt whale classification or hull number identification.

Payload Configuration: In addition to changing flight parameters such as altitude and airspeed, the payload configuration can be modified to optimize the ability of the camera to spot the desired targets. Figure 2 shows how the resolution of each pixel on the screen changes when a relatively wide field of view (40 degrees) is used on a side looking camera (26 degrees below horizontal). See payload detail image below for standard camera position. In order to maximize

the usage of the available screen, the camera may be positioned so that it yields the highest coverage area at the required pixel resolution and camera angle.

Camera angle is important and depends on several factors. One is the orientation of the target object. Ship's numbers will require a camera angle that optimizes their apparent size while a humpback whale may be most optimally found with an above-down view. In addition, the feature size is a factor. Very large features would require very high aircraft altitudes to cover the greatest amount of area if the camera is oriented downwards. A side-looking camera setup in this case gives a larger camera swath while allowing the aircraft to fly at reasonable altitudes.

Figure 2. Pixel Resolution

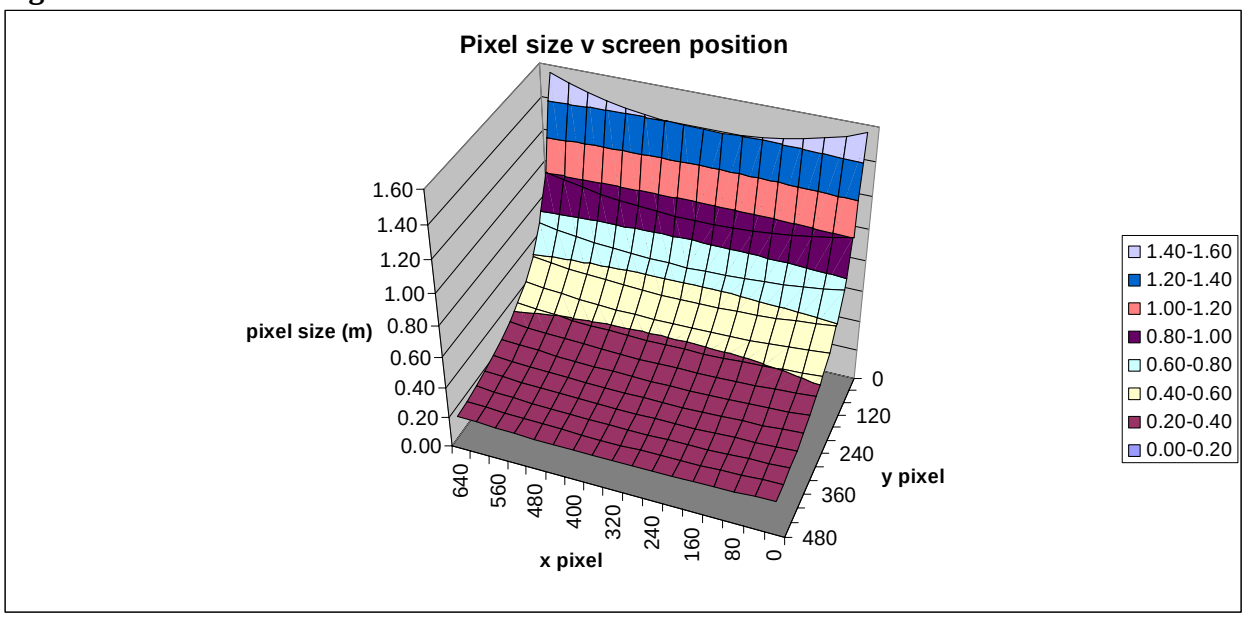
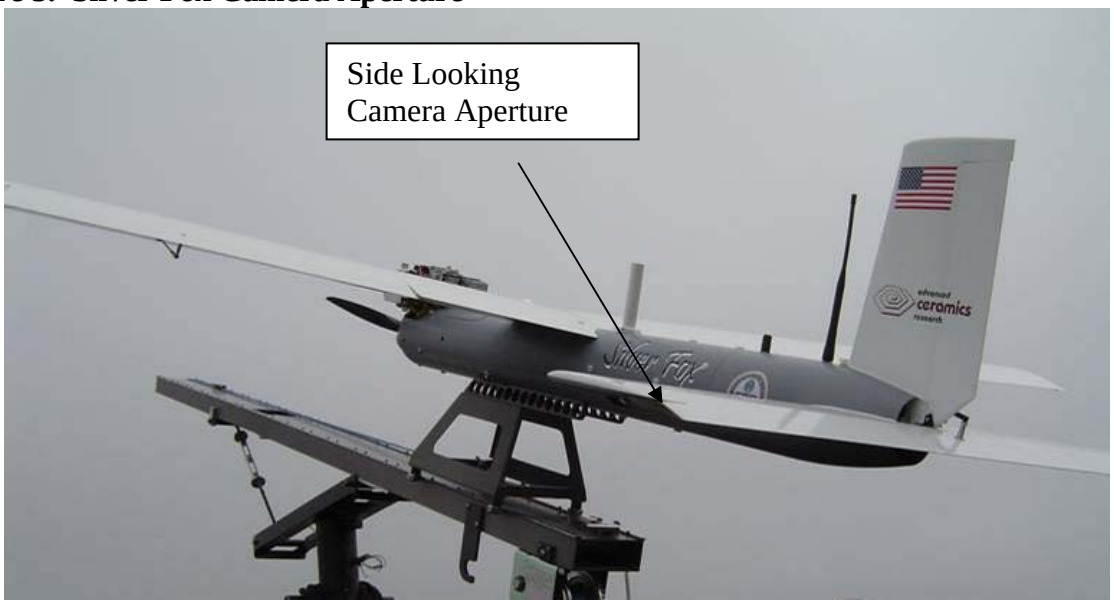


Figure 3. Silver Fox Camera Aperture



2.1.1 EO/IR Camera Primary Objectives

1) ***Prove platform capabilities for counting humpback whales and vessels.*** Flights will be down to 300m over the water.
2) ***Oil spill and algae bloom tracking.*** At higher altitudes with larger search swaths, larger areas of ocean or coastline can be covered. As seen in figure one, several hundred square kilometers can be covered at resolutions permitting the detection of large features.

2.1.2 EO Secondary Objectives

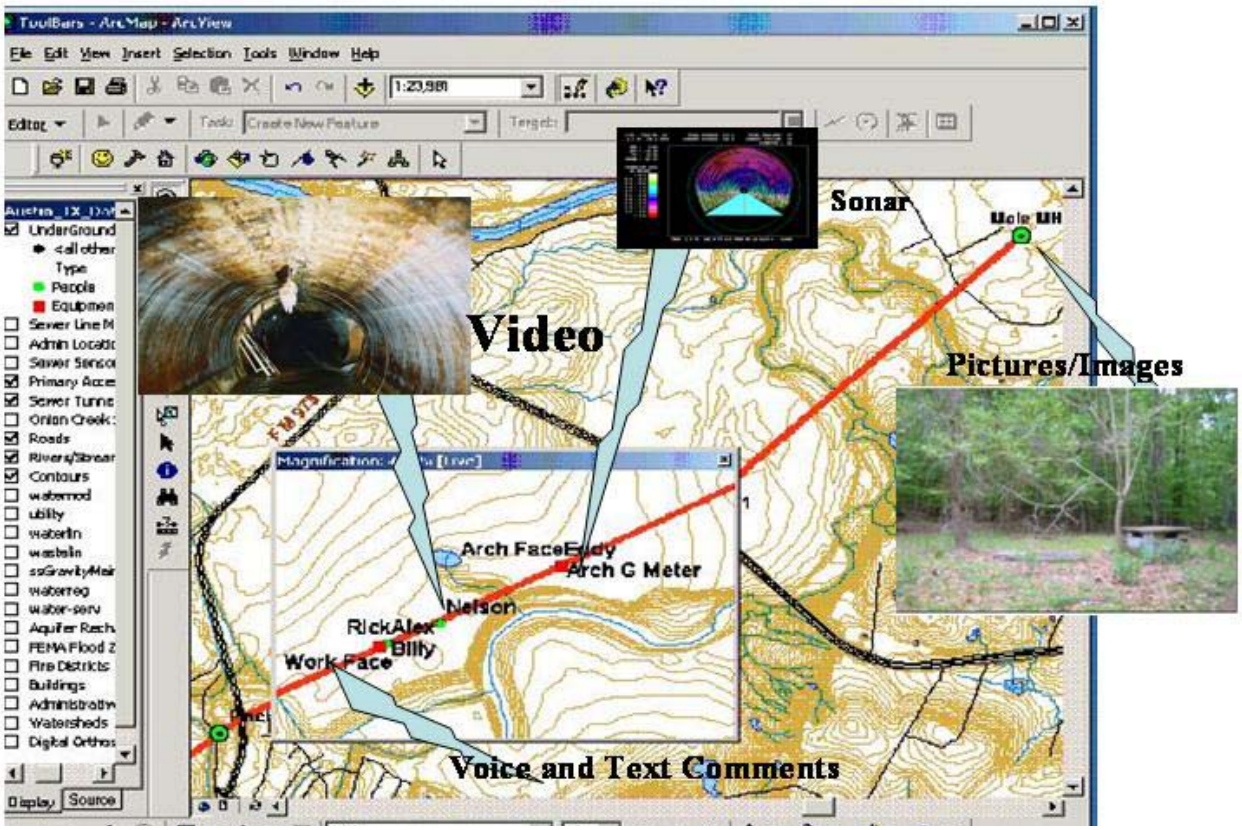
1) ***Surveillance/Enforcement.*** Prove the EO/IR capabilities for surveillance/enforcement of fishing and marine mammal protection regulations. Flight in and out of inclement weather is preferred, as is both night and day operations to prove capability. Real-time downlink as well as ability to view over the Internet is required for enforcement purposes. Prove ability to properly identify and position targets as well as transmit data.
3) ***Enforcement/Surveillance.*** During whale observation exercises with the video camera, the camera may also acquire imagery of active fishing vessels as well as non-fishing vessels. These vessels will be spotted and targeted, photographed and logged by the system.

2.2 Imagery Analysis - Ambiente

Ambiente is a temporal and spatial Geographic Information System (GIS) that may be accessed by the Internet. It is the kernel of an information system that manages data and information of a temporal and spatial nature so that all of the data and information may be viewed in the same

datum and projection. The unique aspect of this type of GIS implementation is that it combines temporal (e.g,, weather, resource counts, images) data and information with "classic" GIS data (maps and charts) that are feeding GIS applications today. With the use of Ambiente the user is able to see the entire region of interest on the same map and add resource status information to support a management need.

Figure 4 Ambiente View 1



Ambiente will increase the effectivness of the imagery and data collected by the Silver Fox, by presenting it in a comprehensive manner.

3.0 Flight Planning Information

Baseline flight profiles. Flights conducted under the proposed work are categorized into two different classes: checkout and operational flights. The checkout flights will be relatively short and local to the Maui or Kauai areas, while the missions will be of relatively longer duration and distance from the offshore. The mission flights will be based on operational surveillance goals (see Section 1.1).

Silver Fox performance specifications. The Silver Fox UAS can be operated for up to 8 hours at altitudes up to 10,000 feet. The Silver Fox true air speed ranges from 35 to 55 kts. The operating range will be approximately 320 nautical miles. Winds at cruise altitude and time-on-station will affect the operating range on individual flights. Note that the communications range is limited by the video to 20nmi from a receiving station, though the receiver need not be in the

same location as the launch or control facilities. Future flights may be conduced beyond line of sight (BLOS) with the integration of satellite modems. To accomplish the objectives of these experiments, flights within line of sight are sufficient.

Table 2. Summary of Silver Fox Flight Plans

Flight category	Specifications
Checkout flight(s)	**Location:** Restricted air space over the Upolu Point area. **Purpose:** Functional test of all sensor systems. **Requirement:** Access to air space, clear weather, and greater than 3 hr duration
National Marine Sanctuary Flight Set #1	**Location:** The airspace above and around the Upolu Point area. **Purpose:** Marine mammals: Attempt to duplicate or exceed accuracy and image resolution of manned survey missions. Evaluate utility of UASs as platforms for remote marine mammal survey and census.
National Marine Sanctuary Flight Set #2	**Location:** The airspace above and around Upolu Point area. (Exact geographic areas TBD by daily fishing and recreational vessel activity.) **Purpose:** Vessels, marine debris, plume mapping: To record fishing and boat activity, marine debris and to map plumes. Identify and record general vessel activity and evaluate identification capabilities of the EO/IR.
National Marine Sanctuary Flight Set #3	**Location:** Nearshore airspace along the Upolu Point area. **Purpose:** Record images of nearshore benthic habitats out to depths that preclude imaging.

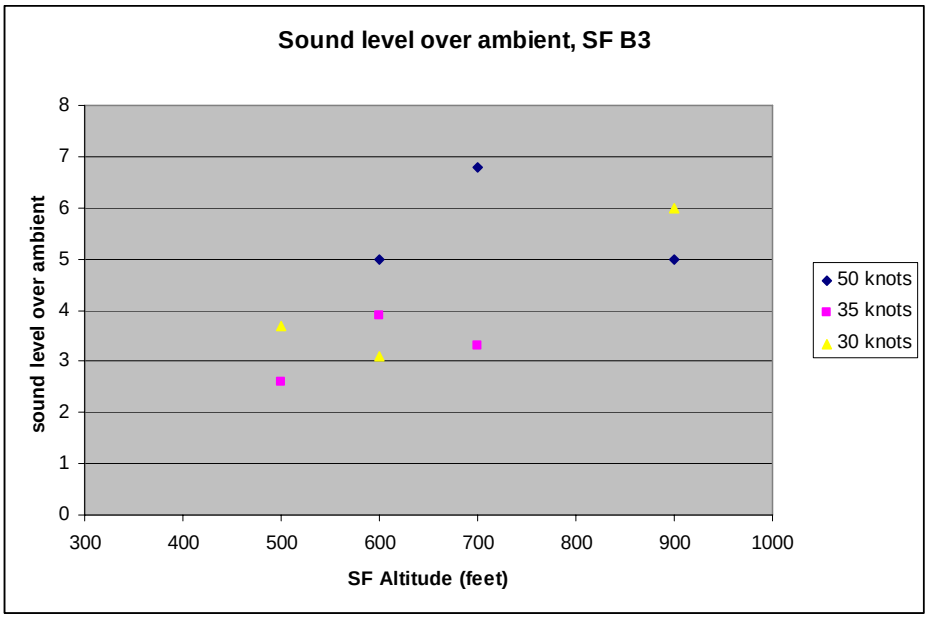
4.1 Checkout Flight(s)

Location: The airspace above and around the HIHWNMS, in the vicinity of Upolu Point.
Purpose: Checkout of vehicle and all camera and communication systems.
Requirements: Clear weather over the water and access to airspace.
Criteria for Success: Operation over the full range of altitudes and climb/descent rates that will be encountered during the mission flights.

4.2 National Marine Sanctuary Flight Set #1

This flight would demonstrate day/night operations to perform remote (>300m altitude) humpback whale survey and census. Flights would be performed at minimal altitudes of 300m to evaluate resolution. Encounters below 300 m may occur during takeoff and landing, or when other operations are underway. In such cases, sound level measurements performed at ACR at various altitudes and airspeeds indicate that even at levels around 150 m, the sound level on the ground directly under the aircraft would not exceed more than 7 dB above ambient (see Figure 5).

Figure 5. Sound Level Measurements



Mission Goals: Perform humpback whale survey and census.

Mission Location: Location will focus on the Upolu Point area.

Mission Purpose: Attempt to duplicate or exceed accuracy and image resolution of manned survey missions by detecting and surveying the humpback whale population in the vicinity of the flight operations.

4.3 National Marine Sanctuary Flight Set #2

This flight would demonstrate day/night operations to capture imagery of boat and fishing activity by capturing visible light reflectance and infrared imagery. Flights at 100m to 1000 m will be flown (see resolutions and configurations in Figure 1). Lower flights may be required for specific identification of commercial and recreational fishery vessels, and other items of interest (marine debris, plumes, etc).

Mission Goals: Day/night operations to utilize the EO/IR to survey fishery vessel use patterns in the HIHWNMS.

Mission Location: Location will focus on the Upolu Point area. (Exact geographic areas TBD by daily fishing and shipping activity.)

Mission Purpose: Attempt to duplicate or exceed accuracy and image resolution of manned survey missions by recording and identifying vessel types, locations, and activities and evaluate utility of UASs as platforms for marine enforcement and spill, debris, and bloom surveillance.

4.4 National Marine Sanctuary Flight Set #3

This flight would demonstrate the ability of the aircraft to image shallow-water habitats and allow for later measurement and targeted ground-truthing and characterization.

Mission Goals: Daytime operations to image coastal benthic habitats and offshore habitats to the depth limits of bottom detection.

Mission Location: Location will focus on the Upolu Point area, at locations with substantial shallow water habitat accessible to snorkelers. (Exact geographic areas TBD.)

Mission Purpose: Attempt to duplicate or exceed habitat detection abilities of manned overflights.

4.5 Airspace considerations

In order to comply with the FAA's guidance on UAS operations, the Silver Fox will be flown within sight of a trained observer in direct PTT radio contact with the UAS operator. This will provide for See and Avoid capability in case of airspace conflict with other aircraft. It is anticipated that future operational UAS flights will not require a local manned observer as the FAA and industry progress towards more ready integration of UASs into the national airspace.

Table 3. Silver Fox Specifications

Parameter	Value (US)	Value (Metric)
Maximum Gross Takeoff Weight (MGTW)	27.0 lbs	12.2 kg
Nominal Mission Takeoff Weight (NMTW)	26.2 lbs	11.88 kg
Nominal Mission Endurance (MOGAS)	8-10 hours	
Fuel Type	Unleaded MOGAS (87 oct. min.)	
Airspeed (Cruise @ NMTW)	38-50 kts	70-90 kph
Airspeed (Dash - level flight @ NMTW)	55 kts	102 kph
Airspeed (Max. Endurance @ NMTW)	35 kts	65 kph
Airspeed (Stall @ NMTW)	28 kts	52 kph
Airspeed (VNE @ NMTW)	110kts	203 kph
Navigation	DGPS/GPS, DGPS/GPS/INS[1]	
Nominal Mission Altitude	500-1200 ft. AGL	150-365 meters AGL
Service Ceiling	12,000 ft. MSL	3657 meters MSL
Launch	Small Footprint Catapult (<75lbs.)	Small Footprint Catapult (<34kgs.)
Recovery	Belly Skid	
Payload (EO)	Daylight, RS-170A Std., 10X optical zoom	
Payload (IR)	320x240, uncooled IR	
Command and Control Radio (C2)	Up to 2 watt, discrete/frequency agile, Military Band / ISM Band Radio Modem (TX/RX)	
Command and Control Radio Range[2]	20 nm, Line of Sight(LOS)	36 km, Line of Sight(LOS)
Video Transmitter	2 Watt (optional 5W), S-Band FM Video TX with optional 19.2kbps data carrier	
Video Transmission Frequency Range	S-Band, L-Band	
Video System Range	20 nm, LOS	36 km, LOS
Payload Capacity	5.0 lbs	2.2 kgs
Onboard Power	BA5590/5390 LiSO2 Battery	
Nominal Mission Fuel Capacity	90 ounces	2.6 Liters
Engine	1-cylinder (25cc), SOHC, 4-stroke, reciprocating engine with oiling system.	
Ignition	Electronic, Capacitive Discharge	
Propulsion	17x8, tractor propeller	
Starting Method	hand-held electric starter (12V)	
Shipping Size	60" X 14" X 16" composite box with wheels	1.52m X 35cm X 40cm composite box with wheels
Wingspan	94 inches	2.4 meters
Fuselage Length	58 inches	1.47 meters
Tail Height	11 inches	28 cm
Fueslage Diameter	5 inches	12.7 cm

[1] - GPS/INS option available Q1, 2006

Note: Air vehicle weights, endurance and link ranges can vary significantly dependant on variant used and mission conditions. Always contact ACR with specific requirements and for further clarification.